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# The FMS MOM4 User Guide

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[FAQs \[http://www.gfdl.gov/~gtm/mom4\\_faq.html\]](http://www.gfdl.gov/~gtm/mom4_faq.html)

[MOM4beta3 email \(frozen\) \[http://www.gfdl.gov/~gtm/mom4beta3\\_email.html\]](http://www.gfdl.gov/~gtm/mom4beta3_email.html)

[MOM4p0 email \[http://www.gfdl.gov/~gtm/mom4\\_email.html\]](http://www.gfdl.gov/~gtm/mom4_email.html)

## 1. Introduction

### 1.1. What is MOM?

The Modular Ocean Model (MOM) is a numerical representation of the ocean's hydrostatic primitive equations, and it is designed primarily as a tool for studying the global ocean climate system. MOM4 is the latest version of the GFDL ocean model whose origins date back to the pioneering work of Kirk Bryan and Mike Cox in the 1960s-1980s. It is developed and supported by researchers at NOAA's Geophysical Fluid Dynamics Laboratory ([GFDL \[http://www.gfdl.noaa.gov\]](http://www.gfdl.noaa.gov)), with contributions also provided by researchers worldwide.

MOM4 was released to the public in January of 2004. As with previous MOM versions, the developers welcome feedback, both positive and negative, on the code's integrity and portability. It is through such feedback that the code evolves and becomes more robust and user friendly.

The purpose of this web page is to provide general information about MOM4 and particular information for how to download and run the code.

## 1.2. MOM4 registration

MOM4 users can acquire the source code and associated data sets from [GForge](http://fms.gfdl.noaa.gov/) [http://fms.gfdl.noaa.gov/], and are required to [register](https://fms.gfdl.noaa.gov/account/register.php) [https://fms.gfdl.noaa.gov/account/register.php] at the [GFDL GForge location](http://fms.gfdl.noaa.gov/) [http://fms.gfdl.noaa.gov/]. Therefore, users need to register only once to get both the source code and datasets of MOM4. More details can be found in the [quickstart\\_guide.html](#).

## 1.3. MOM4 email list

Email concerning MOM4 are to be directed to the mom4-email list located at <oar.gfdl.mom4p0@noaa.gov>. All questions, comments, and suggestions are to be referred to this list. An archive of all emails is maintained at [email archive](http://fms.gfdl.noaa.gov/mail/?group_id=5) [http://fms.gfdl.noaa.gov/mail/?group\_id=5]. A subject-organized archive of the emails is available at [http://www.gfdl.noaa.gov/~gtm/mom4\\_email.html](http://www.gfdl.noaa.gov/~gtm/mom4_email.html). Note that by registering at GForge to access the code, you are automatically subscribed to the email list.

## 1.4. MOM4.0: January 2004

MOM4 has undergone roughly 1.5 years of beta-testing. During this time, numerous researchers throughout the MOM community have provided essential input to the development of the code and its portability to various machines. As a result, a number of bugs were identified and resolved, further diagnostic and functional capabilities added, all resulting in increased code integrity.

Out of the MOM4-beta-testing period grew an understanding of methods useful in Fortran 90 to organize model data flow. Motivated by the goals of using MOM4 for applications such as coupled modeling and ocean data assimilation, the MOM4 developers decided to employ derived data types in MOM4. Derived types (1) allow inputs and outputs to routines to be clearly defined and protected with the Fortran 90 intent attribute, (2) render algorithmic changes requiring additional variables to be easily embedded within the type structures, and (3) reduce dependencies between modules thus leading to enhanced modularity. Overall, derived types lead to increased code clarity and a more robust and easier architecture for future development.

## 1.5. Ongoing issues

The beta-testing period also identified portability and efficiency issues that remain a top priority for GFDL software engineers. In particular, use of MOM4 on the SGI Origin machine used at GFDL saw a sizable reduction in efficiency relative to similar experiments with MOM3.1. Research identified the use of array syntax for dynamically allocated arrays to be at the root of the problem. Compiling the model with static allocation (array sizes specified at compile time) leads to a factor of two speed-up relative to the default dynamic allocation (array sizes allocated at run-time). We are unaware of whether similar behaviour exists on other computer platforms. Compiler engineers at SGI are presently addressing the issues, with the hoped-for result being the elimination of the compiler "feature" leading to the slow-down. Until then, MOM4 will maintain the ability to run with either static or dynamically allocated arrays. The distinction is facilitated by a cpp-preprocessor option, with dynamical allocation the default.

## 2. Details of MOM4

### 2.1. Documentation

In addition to this user guide, documentation for MOM4 is provided by two LaTeX generated postscript documents:

1. [A Technical Guide to MOM4](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/guide.pdf) [[http://www.gfdl.noaa.gov/~smg/pointers/geo\\_physics\\_abstracts/guide.pdf](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/guide.pdf)] by [<Stephen.Griffies@noaa.gov>](mailto:Stephen.Griffies@noaa.gov), [<Matthew.Harrison@noaa.gov>](mailto:Matthew.Harrison@noaa.gov), [<Ronald.Pacanowski@noaa.gov>](mailto:Ronald.Pacanowski@noaa.gov), and [<Tony.Rosati@noaa.gov>](mailto:Tony.Rosati@noaa.gov). This is the primary reference for MOM4. It contains details about some of the numerical algorithms and diagnostics. All usage of MOM4 in the literature should refer to this document:

A Technical Guide to MOM4  
GFDL Ocean Group Technical Report No. 5  
S.M. Griffies, M.J. Harrison, R.C. Pacanowski, and A. Rosati  
NOAA/Geophysical Fluid Dynamics Laboratory  
Available on-line at <http://www.gfdl.noaa.gov/~fms>.

2. A theoretical rationalization of ocean climate models is provided by the manuscript [Fundamentals of Ocean Climate Models](http://www.gfdl.gov/~smg/pointers/geo_physics_abstracts/book.html) [[http://www.gfdl.gov/~smg/pointers/geo\\_physics\\_abstracts/book.html](http://www.gfdl.gov/~smg/pointers/geo_physics_abstracts/book.html)] by Griffies.

### 2.2. Characteristics

Although MOM4 shares much in common with earlier versions of MOM, it possesses a number of computational, numerical, and physical characteristics that are noteworthy. The following provides an overview of the main characteristics of MOM4 (please refer to [A Technical Guide to MOM4](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/guide.pdf) [[http://www.gfdl.noaa.gov/~smg/pointers/geo\\_physics\\_abstracts/guide.pdf](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/guide.pdf)] for references).

- MOM4 is coded in Fortran 90 and physical units are MKS.
- MOM4 meets the code standards set by the GFDL Flexible Modeling System (FMS [<http://www.gfdl.noaa.gov/~fms>]). It also utilizes a substantial number of software infrastructure modules shared by other FMS-based models. In particular, all I/O (e.g., restarts, forcing fields, initial fields) is handled via NetCDF [<http://www.unidata.ucar.edu/packages/netcdf/>].
- There is only a single cpp-preprocessor option, `ifdefs`, associated with the handling of memory in the model. All options for physical and dynamical choices are handled via namelists and/or switching in/out of modules at compile time. Removing `ifdefs` allows for more readable code that possesses a higher level of error checker handling.
- 2D (latitudinal/longitudinal) horizontal domain decomposition is used for single or multiple parallel processors. Correspondingly, 3D arrays are dimensioned (i,j,k) instead of (i,k,j) used in earlier MOMs. MOM4 has no memory window or slabs.
- The model dynamics/kinematics are based on the non-Boussinesq method of Greatbatch et al. (2002). The Boussinesq option is available via a namelist.
- Generalized orthogonal horizontal coordinates are used. GFDL is supporting both the standard spherical coordinates, as well as the "tripolar" grid of Murray (1996). Details are provided in [A Technical Guide to MOM4](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/guide.pdf) [[http://www.gfdl.noaa.gov/~smg/pointers/geo\\_physics\\_abstracts/guide.pdf](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/guide.pdf)].
- Bottom topography is represented using the partial cells of Pacanowski and Gnanadesikan (1998). The older full cell approach is available as a namelist.

- Time stepping for the inviscid dynamics uses the leap-frog method along with a Robert-Asselin time filter. The Euler forward or Euler backward mixing time step used in earlier MOMs has been eliminated.
- The sole external mode solver is a variant of the Griffies et al. (2001) explicit free surface. Top model grid cells have time dependent volume. Details are provided in [Fundamentals of Ocean Climate Models](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/book.pdf) [http://www.gfdl.noaa.gov/~smg/pointers/geo\_physics\_abstracts/book.pdf].
- Neutral tracer physics includes Redi neutral diffusion according to Griffies et al. (1998), and Gent-McWilliams stirring according to the Griffies (1998) skew-flux method. Two-dimensional flow dependent diffusivities are available and determined according to the depth integrated Eady growth rate and Rossby radius of deformation, as motivated by the ideas of Held and Larichev (1996) and Visbeck et al. (1997). Details are provided in [Fundamentals of Ocean Climate Models](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/book.pdf) [http://www.gfdl.noaa.gov/~smg/pointers/geo\_physics\_abstracts/book.pdf].
- McDougall et al. (2003) equation of state has been implemented, with in situ density a function of the local potential temperature, salinity, and hydrostatic pressure (baroclinic pressure plus free surface pressure plus atmospheric pressure). Details are provided in [A Technical Guide to MOM4](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/guide.pdf) [http://www.gfdl.noaa.gov/~smg/pointers/geo\_physics\_abstracts/guide.pdf].
- Vertical mixing schemes include the time-independent depth profile of Bryan and Lewis (1979), the Richardson number dependent scheme of Pacanowski and Philander (1981), and the KPP scheme of Large et al. (1994).
- Horizontal friction schemes include uniform and grid dependent viscosity schemes, as well as the shear-dependent Smagorinsky viscosity according to Griffies and Hallberg (2000). The anisotropic scheme of Large et al. (2001) and Smith and McWilliams (2002) has been implemented. Details are provided in [Fundamentals of Ocean Climate Models](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/book.pdf) [http://www.gfdl.noaa.gov/~smg/pointers/geo\_physics\_abstracts/book.pdf].
- Tracer advection is available using 2nd, 4th, 6th order centered schemes as documented in [The MOM3 Manual of Pacanowski and Griffies \(1999\)](http://www.gfdl.gov/~smg/MOM/web/guide_parent/guide_parent.html) [http://www.gfdl.gov/~smg/MOM/web/guide\_parent/guide\_parent.html], and the quicker scheme documented by Holland et al. (1998) as well as [The MOM3 Manual](http://www.gfdl.gov/~smg/MOM/web/guide_parent/guide_parent.html) [http://www.gfdl.gov/~smg/MOM/web/guide\_parent/guide\_parent.html]. Additionally, two multi-dimensional flux limited schemes have been ported from the MIT model, and these schemes are monotonic. Note that the 4th and 6th order algorithms assume constant grid spacing, which simplifies the code though compromises accuracy on non-uniform grids.
- Topographically oriented tracer diffusion introduces enhanced diffusion when heavy parcels are above lighter parcels. It is implemented according to the ideas of Beckmann and Döscher (1997) and Döscher and Beckmann (1999). Details are provided in [A Technical Guide to MOM4](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/guide.pdf) [http://www.gfdl.noaa.gov/~smg/pointers/geo\_physics\_abstracts/guide.pdf].
- The "overflow" scheme of Campin and Goosse (1999) has been implemented, whereby gravitationally unstable fluid parcels are allowed to move downslope via an upwind advection scheme.
- Penetration of shortwave radiative heating into the upper ocean is generally attenuated by the inclusion of chlorophyll data.
- Tidal forcing from the various lunar components are available to force the free ocean surface.
- Open boundary conditions are available to allow open boundaries in either of the north, south, east, or west directions.
- MOM4 comes with three tracer packages: (1) ideal age tracer (2) tracers for the OCMIP biotic protocol (3) CFC tracers. Additionally, a suite of code is available for handling tracers inside MOM4 and FMS shared code ([field\\_manager](#) [../src/shared/field\_manager/field\_manager.html]). This code provides the user with many options for adding new tracer packages, ecosystem models, etc.
- MOM4 has numerous diagnostics for checking algorithm and solution integrity. These diagnostics include budgets for energetic consistency, tracer conservation, solution stability, etc. Additional diagnostics are available for numerous fields of relevance to the different physics schemes, as well as term balances.
- As a forward model, MOM4 is compatible with the most recent automatic differentiation tool of Ralf Giering and Thomas Kaminski. See their FastOpt home page at <http://www.FastOpt.com/frameset.html> for more details.

## 2.3. MOM4 and FMS

MOM4 has been coded within GFDL's Flexible Modeling System ([FMS](http://www.gfdl.noaa.gov/~fms) [<http://www.gfdl.noaa.gov/~fms>]). Doing so allows for MOM4 developers to use numerous FMS infrastructure and superstructure modules that are shared amongst various atmospheric, ocean, sea ice, land, vegetative, etc. models. Common standards and shared software tools facilitate the development of high-end earth system models, which necessarily involves a wide variety of researchers working on different computational platforms. Such standards also foster efficient input from computational scientists and engineers as they can more readily focus on common computational issues.

The following list represents a sample of the FMS shared modules used by MOM4.

- [time manager](#) [[../src/shared/time\\_manager/time\\_manager.html](#)]: keeps model time and sets time dependent flags
- [coupler](#) [[../src/coupler/coupler\\_main.html](#)]: used to couple MOM4 to other component models
- [I/O](#) [[../src/shared/mpp/mpp\\_io.html](#)]: to read and write data in either NetCDF, ASCII, or native formats
- [parallelization tools](#) [[../src/shared/mpp/mpp.html](#)]: for passing messages across parallel processors
- [diagnostic manager](#) [[../src/shared/diag\\_manager/diag\\_manager.html](#)]: to register and send fields to be written to a file for later analysis
- [field manager](#) [[../src/shared/field\\_manager/field\\_manager.html](#)]: for integrating multiple tracers and organizing their names, boundary conditions, and advection schemes

The FMS infrastructure (the "Jakarta version") has been released to the public on [GForge](#) [<http://fms.gfdl.noaa.gov/>], with further releases every three-four months. Notably, the release of MOM4 represents the first major model code to be released using the FMS infrastructure.

The Flexible Modeling System ( [FMS](#) [<http://www.gfdl.noaa.gov/~fms>]) is free software; you can redistribute it and/or modify it and are expected to follow the terms of the GNU General Public License as published by the Free Software Foundation; either version 2 of the License, or (at your option) any later version.

FMS is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.

You should have received a copy of the GNU General Public License along with MOM4; if not, write to:

Free Software Foundation, Inc.  
59 Temple Place, Suite 330  
Boston, MA 02111-1307  
USA  
or see: <http://www.gnu.org/licenses/gpl.html>

## 2.4. Test cases

MOM4 is distributed with a set of test cases located in `mom4/exp/`. These tests are taken from models used at [GFDL](#) [<http://www.gfdl.noaa.gov>] for testing the numerical and computational integrity of the code.



### Warning

These experiments are *NOT* sanctioned for their physical relevance. They are instead provided for the user to learn how to run MOM4, and to verify the numerical and/or computational integrity of the code. *PLEASE* do not assume that the experiments will run for more than the short time selected in the sample runscripts.

`mom4_test1`: flat bottom sector model with simple physics. This model is very small and can be easily run on a single workstation. It should provide the user with a basic experience of running `mom4`.

`mom4_test2`: flat bottom sector model which more fully tests some realistic physics options. This experiment has the same grid as `test1`, but it more thoroughly exercises the various physics packages.

`mom4_test3A`: east-west channel with open boundary at west. This experiment is an illustration of the open boundary condition capability of MOM4. Tracers include potential temperature and salinity.

`mom4_test3B`: solid wall of twice domain size as `test3A` for testing OBC. This experiment is used to verify the relevance of the `test3A` solution at early times. That is, for early times, the solution from `test3A` should agree with that from `test3B`. Tracers include potential temperature and salinity.

`mom4_test4`: global tripolar grid using roughly 3x3 resolution with 28 vertical levels and age, biotic, and cfc tracer packages. Coupled to GFDL sea ice model.

`mom4_test5`: global tripolar grid using roughly "1-degree" resolution ocean with 50 vertical levels coupled to the GFDL sea ice model and forced with the German OMIP dataset. Tracers include potential temperature, salinity, and age.

### 3. Contributing MOM4-modules

As with previous MOMs, the GFDL-MOM4 developers aim to provide the international climate research community with a repository for robust and well documented methods to simulate the ocean climate system. Consequently, we encourage researchers to support various modules that are presently absent from MOM4, yet may arguably enhance the simulation integrity (e.g., a new physical parameterization or new advection scheme) or increase the model's functionality.

Depending on the level of code contributions, we envision a directory where "contributed MOM4 code" will reside. Maintenance and ownership of this code will remain with the contributor. As a practical matter, prior to spending time developing a new module, it is recommended that the developer query the [MOM4 mailing list](mailto:oar.gfdl.mom4p0@noaa.gov) [mailto:oar.gfdl.mom4p0@noaa.gov] to see what efforts in the community may have already been availed.

Requirements that contributed code must meet include the following:

1. clean modular Fortran 90 code that minimally touches other parts of the model
2. satisfaction of the [FMS](http://www.gfdl.noaa.gov/~fms) [http://www.gfdl.noaa.gov/~fms] code specifications outlined in the [FMS Developers' Manual](http://www.gfdl.noaa.gov/~vb/FMSManual/FMSManual.html) [http://www.gfdl.noaa.gov/~vb/FMSManual/FMSManual.html]
3. compatibility with the MOM4 [test cases](#) [#mom4 test cases]
4. thorough and pedagogical documentation of the module for inclusion in [A Technical Guide to MOM4](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/guide.pdf) [http://www.gfdl.noaa.gov/~smg/pointers/geo\_physics\_abstracts/guide.pdf] (a Latex document)
5. comments within the code emulating other parts of the model so that HTML documentation files can be generated by our converter

### 4. Source code and data sets

MOM4 is being released to a limited number of modelers. If you wish to obtain the MOM4 source code and data sets, please complete the [registration form](http://nomads.gfdl.noaa.gov/nomads/forms/mom4_registration.html) [http://nomads.gfdl.noaa.gov/nomads/forms/mom4\_registration.html] described above. After your registration has been received (please allow a few days for email confirmation), you will be provided with a password allowing you access to the [GFDL NOMADS-server](http://nomads.gfdl.noaa.gov/) [http://nomads.gfdl.noaa.gov/] web page containing the MOM4 source code. Please *ALSO* register with the MOM4 web page at [SourceForge](http://lists.sourceforge.net/lists/listinfo/fms-mom4) [http://lists.sourceforge.net/lists/listinfo/fms-mom4], as SourceForge will be the avenue



through which we broadcast information regarding bug-fixes, updates, etc.

During the beta-testing phase, we sincerely request that you share the code *ONLY* with those at your institution who are directly collaborating with you. Full public release of MOM4.0 will occur after critical evaluation by the beta-testers.

## 4.1. Source code and data sets

The [FMS](http://www.gfdl.noaa.gov/~fms) [http://www.gfdl.noaa.gov/~fms] development team uses a local implementation of [GForge](http://fms.gfdl.noaa.gov) [http://fms.gfdl.noaa.gov] to serve FMS software, located at <http://fms.gfdl.noaa.gov>. In order to obtain the source code and data sets, you must [register](https://fms.gfdl.noaa.gov/account/register.php) [https://fms.gfdl.noaa.gov/account/register.php] as an FMS user on our software server. After submitting the registration form on the software server, you should receive an automatically generated confirmation email within a few minutes. Clicking on the link in the email confirms the creation of your account.

After your account has been created, you should [log in](https://fms.gfdl.noaa.gov/account/login.php) [https://fms.gfdl.noaa.gov/account/login.php] and request access to the [Flexible Modeling System](http://www.gfdl.noaa.gov) [http://www.gfdl.noaa.gov] project. Once the FMS project administrator grants you access, you will receive a second email notification. This email requires action on the part of the project administrator and thus may take longer to arrive. The email will contain a software access password along with instructions for obtaining the release package, which are described below.

To check out the release package containing source code, scripts, and documentation via CVS, type the following commands into a shell window. You might wish to first create a directory called `fms` in which to run these commands. You should enter the software access password when prompted by the **cvs login** command. At cvs login, the file `~/ .cvspass` is read. If this file does not already exist, an error message may display and the cvs login may fail. In this event, you should first create this file via **touch ~/.cvspass**.

```
cvs -z3 -d:pserver:cvs@fms.gfdl.noaa.gov:/cvsroot/mom4 login
cvs -z3 -d:pserver:cvs@fms.gfdl.noaa.gov:/cvsroot/mom4 co -r mom4p0b mom4
```

This will create a directory called `mom4` in your current working directory containing the release package.

If you prefer not to use CVS, you may download the tar file from <https://fms.gfdl.noaa.gov/projects/mom4/>. Sample output is also available there for download. See [Section 7.1, “Sample model output”](#) for more information on the sample output.

All data sets that are needed to run [MOM4 test cases](#) [#mom4 test cases] are available for download from the same place in GForge where users get the source code. Therefore, users need to register only once to get both the source code and datasets of MOM4. More details can be found in the [quickstart\\_guide.html](#).

## 4.2. Description of the data sets

The topography data set for `test4` and `test5` is a coarsened version of that kindly provided by Andrew Coward and David Webb at the [Southampton Oceanography Centre](http://www.soc.soton.ac.uk/JRD/OCCAM/welcome.html) [http://www.soc.soton.ac.uk/JRD/OCCAM/welcome.html]. Their topography is a montage of that developed by [Smith and Sandwell](http://topex.ucsd.edu/marine_topo/mar_topo.html) [http://topex.ucsd.edu/marine\_topo/mar\_topo.html] (1997) by satellite data in the region of 72°S to 72°N, the NOAA (1988) 5-minute global topography [ETOPO5](http://www.ngdc.noaa.gov/mgg/global/etopo5.HTML) [http://www.ngdc.noaa.gov/mgg/global/etopo5.HTML], and the International Bathymetric Chart of the Arctic Ocean ([IBCAO](http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html) [http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html]). The chlorophyll-a density data set was compiled by [Colm Sweeney](mailto:Colm.Sweeney@noaa.gov) [mailto:Colm.Sweeney@noaa.gov], using data from [James A. Yoder](http://www.gso.uri.edu/faculty/yoder.html) [http://www.gso.uri.edu/faculty/yoder.html] and Maureen A. Kennelly at the [Graduate School of Oceanography](http://www.gso.uri.edu/) [http://www.gso.uri.edu/], [University of Rhode Island](http://www.uri.edu/) [http://www.uri.edu/]. This data set contains monthly chlorophyll concentrations from the [SeaWiFS](http://seawifs.gsfc.nasa.gov/SEAWIFS.html) [http://seawifs.gsfc.nasa.gov/SEAWIFS.html] satellite for the period 1999-2001. Monthly wind stress is based on Hellerman and Rosenstein (1983). Temperature and salinity initial and boundary conditions are provided by the [NOAA](http://www.noaa.gov) [http://www.noaa.gov] National

Oceanographic Data Center ([NODC](http://www.nodc.noaa.gov/) [<http://www.nodc.noaa.gov/>]) World Ocean Atlas ([WOA](http://www.nodc.noaa.gov/OC5/indprod.html) [<http://www.nodc.noaa.gov/OC5/indprod.html>])).

## 5. Preprocessing steps

### 5.1. Grid generation

The `grid_spec.nc` file is generated by executing the **make\_xgrids** utility. **make\_xgrids** generates the two exchange grids used by the FMS coupler, one for surface fluxes and the other for runoff, when the simulation requires an atmospheric grid different from the sample exchange grids provided by **FMS** [<http://www.noaa.gov/~fms>]. **make\_xgrids** is created by compiling its C source, for example:

```
cc -O -o make_xgrids make_xgrids.c -L/usr/local/lib -lnetcdf -lm
```

creates the **make\_xgrids** executable from C-source and the netCDF and standard math libraries and is executed with the command:

```
make_xgrids -o LON2.5LAT2LONLAT.nc -a N45.nc -l N45.nc
```

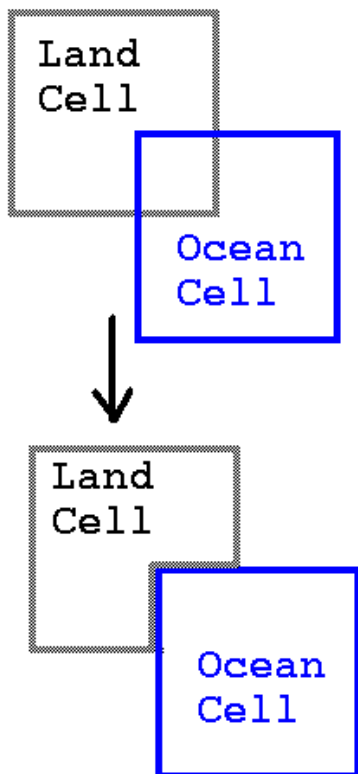
which makes a `grid_spec.nc` file (input files containing grid information for the ocean/sea-ice, atmosphere and land component models are indicated by the `-o`, `-a` and `-l` flags, respectively). **make\_xgrids** expects a netCDF format input specification for the ice/ocean grid ( `LON2.5LAT2LONLAT.nc` in the above example). Three fields are required to be in this file:

1. **wet** - a 2D array of double precision numbers set to 1.0 where the ice and ocean models are active and 0.0 elsewhere. **wet** has **im** indices in the **i** (pseudo east-west) direction and **jm** indices in the **j** (pseudo north-south) direction. These correspond to the global arrays of temperature, salinity and ice thickness in the coupled climate model.
2. **x\_vert\_T** and **y\_vert\_T** - 2D double precision arrays (dimensioned **im+1** by **jm+1**) that contain the longitudes and latitudes (respectively) of the four corners of T- cells in degrees.

**make\_xgrids** also expects a netCDF format input specification for the atmosphere and land grid (`N45.nc` in the above example). **x\_vert\_T** and **y\_vert\_t** are required in the atmosphere/land grid file (`N45.nc`). **make\_xgrids** copies all fields of the ice/ocean grid specification file to its output file, `grid_spec.nc`, and then appends fields that specify the atmosphere and land model grids and the surface and runoff exchange grids.



**make\_xgrids** takes care that the land and ocean grids perfectly tile the



sphere. The land model's domain is defined as the part of the sphere not covered by ocean (where  $wet = 0$  on the ocean grid). To accomplish this, the land cells must be modified to remove the ocean parts. This is done in **make\_xgrids** by first taking the intersections of atmosphere and land cells. The overlap area between these cells and active ocean cells are then subtracted. Finally, the modified atmosphere/land intersections are aggregated into land cell areas and atmosphere/land exchange cell areas.

Model cell intersections are calculated using the Sutherland-Hodgeman polygon clipping algorithm (Sutherland, I. E. and G. W. Hodgeman, 1974: Reentrant polygon clipping, CACM, 17(1), 32-42.). This algorithm finds the intersection of a convex and arbitrary polygon by successively removing the portion of the latter that is "outside" each boundary of the former. It can be found in many computer graphics text books (e.g., Foley, J. D., A. van Dam, S. K. Feiner, and J. F. Hughes, 1990: Computer graphics: principles and practice, second edition. Addison Wesley, 1174 pp.). The implementation in **make\_xgrids** is particularly simple because the clipping polygon is always a rectangle in longitude/latitude space. For the purpose of finding the line intersections in the clipping operations, the cell boundaries are assumed to be straight lines in longitude/latitude space. This treatment is only perfectly accurate for cells bounded by lines of longitude and latitude.

Spherical areas are calculated by taking the integral of the negative sine of latitude around the boundary of a polygon (Jones, P. W., 1999: First- and second-order conservative remapping schemes for grids in spherical coordinates. Monthly Weather Review, 127, 2204-2210.). The integration pathways are again straight lines in longitude/latitude space. **make\_xgrids** checks that the sphere and the individual cells of the atmosphere and ocean grids are tiled by the surface exchange cells. The fractional tiling errors are reported.

## 6. Preparing the runscript

### 6.1. The runscript

A runscript is provided in each [test case](#) [#mom4 test cases] directory (`mom4/exp/$test_case` ) for each [test case](#) [#mom4 test cases]. Details can be found in [quickstart\\_guide.html](#).

Incorporated in the FMS infrastructure is [MPP](#) [[../src/shared/mpp/mpp.html](#)] (Massively Parallel Processing), which provides a uniform message-passing API interface to the different message-passing libraries. If MPICH is installed, the user can compile the MOM4 source code with MPI. If the user does not have MPICH or the communications library, the MOM4 source code can be compiled without MPI by omitting the CPPFLAGS value -Duse\_libMPI in the example runscript.

## 6.2. The diagnostics table

The diagnostics table allows users to specify the sampling rates and choose the output fields prior to executing the MOM4 source code. It is included in the input directory for each [test case](#) [#mom4 test cases] (mom4/exp/\$test\_case/input). A portion of a sample MOM4 diagnostic table is displayed below. Reference [diag\\_table\\_tk.html](#) [[../src/shared/diag\\_manager/diag\\_table\\_tk.html](#)] for detailed information on the diagnostics table.

```
"Diagnostics for MOM4 test case"
1980 1 1 0 0 0
#output files
"ocean_month",1,"months",1,"hours","Time"
"ocean_snap",1,"days",1,"hours","Time"
#####diagnostic field entries#####
#=====
# ocean model grid quantities (static fields and so not time averaged))
"ocean_model","geolon_t","geolon_t","ocean_month" "all",.false., "none",2
"ocean_model","geolat_t","geolat_t","ocean_month","all",.false., "none",2
#=====
# prognostic fields
"ocean_model","temp","temp","ocean_month",all,.true., "none",2
"ocean_model","age_global","age_global","ocean_month","all",.true., "none",2
#=====
# diagnosing tracer transport
"ocean_model","temp_xflux_sigma","temp_xflux_sigma","ocean_month","all",.true., "none"
"ocean_model","temp_yflux_sigma","temp_yflux_sigma","ocean_month","all",.true., "none"
#=====
# surface forcing
"ocean_model","sfc_hflux","sfc_hflux","ocean_month","all",.true., "none",2
"ocean_model","sfc_hflux_adj","sfc_hflux_adj","ocean_month","all",.true., "none",2
#=====
# ice model fields
"ice_model","FRAZIL","FRAZIL","ice_month","all",.true., "none", 2,
"ice_model","HI","HI","ice_month","all",.true., "none", 2
#-----
```

The diagnostics manager module, [diag\\_manager\\_mod](#) [[../src/shared/diag\\_manager/diag\\_manager.html](#)], is a set of simple calls for parallel diagnostics on distributed systems. It provides a convenient set of interfaces for writing data to disk, namely in [NetCDF](#) [<http://www.unidata.ucar.edu/packages/netcdf/>] format. The diagnostics manager is packaged with the MOM4 source code. The FMS diagnostic manager presently cannot handle scalar fields that are functions of time for technical reasons. This limitation of the FMS diagnostic tool will be remedied. Until then, scalars sent to the diagnostic manager are given a vertical dimension, with each value in the vertical the same. For more information on the diagnostics manager, reference [diag\\_manager.html](#) [[../src/shared/diag\\_manager/diag\\_manager.html](#)].

## 6.3. The field table

The MOM4 field table is used to specify tracers and their advection schemes, cross-land tracer mixing and check-board smoothing. The field table is included in the runscript as a namelist and is written to an output file upon

execution of the runscript.

```
# Tracers

"tracer","ocean_mod","temp"
  "advection_scheme_horiz","quicker"
  "advection_scheme_vert","quicker"
  "longname","potential temperature"/

"tracer","ocean_mod","salt"
  "advection_scheme_horiz","quicker"
  "advection_scheme_vert","quicker"
  "longname","salinity"/

"tracer","ocean_mod","test"
  "advection_scheme_horiz","4th_order"
  "advection_scheme_vert","4th_order"
  "longname","test passive tracer"/

# Cross-land mixing

"xland_mix","ocean_mod","xland_mix"
"xland","$EXPERIMENT","ixland_1=4,ixland_2=6,jxland_1=20,jxland_2=22,kxland_1=1,kxland_2=2"
"xland","$EXPERIMENT","ixland_1=15,ixland_2=16,jxland_1=2,jxland_2=3,kxland_1=3,kxland_2=4"

# Checkerboard null mode

"checkerboard","ocean_mod","checkerboard"
"check","$EXPERIMENT","i=15,j=11,mix_vel=.50"
"check","$EXPERIMENT","i=1,j=3,mix_vel=.50"/
```

In the first section of the field table, the user can specify tracers to be used in the simulation. Although there is no limit to the amount of tracers specified, temperature (`temp`) and salinity (`salt`) must be included. The user may also define the horizontal and vertical tracer advection schemes.

In climate modeling, it is often necessary to allow water masses that are separated by land to exchange tracer and surface height properties. This situation arises in models when the grid mesh is too coarse to resolve narrow pas-

sageways that in reality provide crucial connections between water masses. The cross-land mixing establishes communication between bodies of water separated by land. The communication consists of mixing tracers and volume between non-adjacent water columns. Momentum is not mixed. The scheme conserves total tracer content, total volume, and maintains compatibility between the tracer and volume budgets.

Discretization of gravity waves on a B-grid can admit a stationary grid scale checkerboard pattern (e.g., Killworth et al., 1991). This pattern is associated with an unsuppressed grid splitting that can be initiated through grid scale forcing, such as topography, or indeed any forcing that projects onto the grid scale, such as fresh water forcing. The field table contains specifications for selectively enhancing the smoothing provided by the `ocean_checkerboard.F90` module.

For a technical description of cross-land tracer mixing and checkerboard null mode, please reference [A Technical Guide to MOM4](http://www.gfdl.noaa.gov/~smg/pointers/geo_physics_abstracts/guide.pdf) [http://www.gfdl.noaa.gov/~smg/pointers/geo\_physics\_abstracts/guide.pdf].

## 6.4. mppnccombine

Running the MOM4 source code in a parallel processing environment will produce one output [NetCDF](http://www.unidata.ucar.edu/packages/netcdf/) [http://www.unidata.ucar.edu/packages/netcdf/] diagnostic file per processor. `mppnccombine` [./postprocessing/mppnccombine.c] joins together an arbitrary number of data files containing chunks of a decomposed domain into a unified [NetCDF](http://www.unidata.ucar.edu/packages/netcdf/) [http://www.unidata.ucar.edu/packages/netcdf/] file. If the user is running the source code on one processor, the domain is not decomposed and there is only one data file. `mppnccombine` [./postprocessing/mppnccombine.c] will still copy the full contents of the data file, but this is inefficient and `mppnccombine` [./postprocessing/mppnccombine.c] should not be used in this case. Executing `mppnccombine` [./postprocessing/mppnccombine.c] is automated through the `runscripts` [#runscript]. The data files are [NetCDF](http://www.unidata.ucar.edu/packages/netcdf/) [http://www.unidata.ucar.edu/packages/netcdf/] format for now, but IEEE binary may be supported in the future.

`mppnccombine` [./postprocessing/mppnccombine.c] requires decomposed dimensions in each file to have a `domain_decomposition` attribute. This attribute contains four integer values: starting value of the entire non-decomposed dimension range (usually 1), ending value of the entire non-decomposed dimension range, starting value of the current chunk's dimension range and ending value of the current chunk's dimension range. `mppnccombine` also requires that each file have a `NumFilesInSet` global attribute which contains a single integer value representing the total number of chunks (i.e., files) to combine.

The syntax of `mppnccombine` [./postprocessing/mppnccombine.c] is:

```
mppnccombine [-v] [-a] [-r] output.nc [input ...]
```

**Table 1. mppnccombine arguments**

-v	print some progress information
-a	append to an existing <a href="http://www.unidata.ucar.edu/packages/netcdf/">NetCDF</a> [http://www.unidata.ucar.edu/packages/netcdf/] file
-r	remove the '####' decomposed files after a successful run

An output file must be specified and it is assumed to be the first filename argument. If the output file already exists, then it will not be modified unless the option is chosen to append to it. If no input files are specified, their names will be based on the name of the output file plus the extensions '.0000', '.0001', etc. If input files are specified, they are assumed to be absolute filenames. A value of 0 is returned if execution is completed successfully and a value of 1 indicates otherwise.

The source of `mppnccombine` [`../postprocessing/mppnccombine.c`] is packaged with the MOM4 module in the `postprocessing` directory. `mppnccombine.c` should be compiled on the platform where the user intends to run the FMS MOM4 source code so the `runscript` [`#runscript`] can call it. A C compiler and `NetCDF` [<http://www.unidata.ucar.edu/packages/netcdf/>] library are required for compiling `mppnccombine.c`:

```
cc -O -o mppnccombine -I/usr/local/include -L/usr/local/lib mppnccombine.c -lnetc
```

## 7. Examining the output

### 7.1. Sample model output

Sample MOM4 model output data files are available to [registered](#) [`#source code and data sets`] MOM4 users on GFDL's [NOMADS server](http://data1.gfdl.noaa.gov/nomads/forms/mom_beta.html) [[http://data1.gfdl.noaa.gov/nomads/forms/mom\\_beta.html](http://data1.gfdl.noaa.gov/nomads/forms/mom_beta.html)]. The output data are organized into directories that bear the same names as the [test cases](#) [`#mom4 test cases`]. For example, output for test case `test5` can be found in directory `test5`. Output files are classified into three subdirectories:

- `ascii`: the description of the setup of the run and verbose comments printed out during the run.
- `restart`: the model fields necessary to initialize future runs of the model.
- `history`: output of the model, both averaged over specified time intervals and snapshots.

Note that these output files are compressed using `tar`. All `.tar` files should be decompressed for viewing. The decompress command is:

```
tar -xvf filename.tar
```

### 7.2. Analysis tools

There are several graphical packages available to display the model output. These packages vary widely depending on factors, such as the number of dimensions, the amount and complexity of options available and the output data format. The data will first have to be put into a common format that all the packages can read. FMS requires the data to be stored in `NetCDF` [<http://www.unidata.ucar.edu/packages/netcdf/>] format since it is so widely supported for scientific visualization. The graphical package is also dependent upon the computing environment. For ocean modeling, `ncview` [[http://meteora.ucsd.edu/~pierce/ncview\\_home\\_page.html](http://meteora.ucsd.edu/~pierce/ncview_home_page.html)], `Ferret` [<http://ferret.wrc.noaa.gov/Ferret/>] and `GrADS` [<http://grads.iges.org/grads/>] are most commonly used.

## 8. Code updates

### 8.1. MOM4p0b updates

This is a list of files that are modified after the release of MOM4p0a code.

<a href="#">shared/exchange/xgrid.html</a>	Minor edits to make the code compliant with IFC version 8.
<a href="#">ice_param/ocean_albedo.f</a>	Minor edits to make the code compliant with IFC version 8.
<a href="#">90 [../src/ice_param/</a> <a href="#">shared/</a> <a href="#">ocean_albedo.html</a>	Minor edits to make the code compliant with IFC version 8.
<a href="#">column_diagnostics/column</a> <a href="#">shared/horiz</a> <a href="#">diagnostics.f90 [../src/</a> <a href="#">iz_interp/horiz_interp.f</a>	Change the step size of radial search from 1 to 100. This will improve the efficiency and a workaround to fix a bug.
<a href="#">90 [../src/shared/horiz_interp/</a> <a href="#">column_diagnostics/gener</a> <a href="#">ate_grids/ocean/topog.f9</a>	Modify io format to fix one error message.
<a href="#">0 [../src/preprocessing/gener</a> <a href="#">ate_grids/ocean/ocean_gr</a> <a href="#">id_generator.csh [../src/pre</a> <a href="#">processing/generate_grids/ocean/</a> <a href="#">ocean_grid_generator.html</a>	Minor comments update
<a href="#">shared/</a> <a href="#">mpp/mpp_read_2Ddecomp.h</a> <a href="#">shared/diag_manager [../src/</a> <a href="#">shared/diag_manager/</a> <a href="#">mpp_read_2Ddecomp.h]</a> <a href="#">diag_manager.html]</a> <a href="#">coupler/coupler_main.f90</a> <a href="#">[../src/coupler/coupler_main.html]</a>	Added optional argument "time_method" to write_meta_field subroutine. This is used by diag_manager to document how a diagnostic is manipulated along the time axis, e.g. averaging, max, min. The metadata used are compliant with CF1.0 metadata standard.
<a href="#">drivers/ocean_solo.F90</a> <a href="#">[../src/mom4/drivers/</a> <a href="#">postprocessing/regrid [../</a> <a href="#">ocean_solo.html]</a> <a href="#">postprocessing/regrid/regrid.html]</a>	Bug fix for lenx and leny variables
<a href="#">ocean_core/ocean_domains</a> <a href="#">.F90 [../src/mom4/ocean_core/</a> <a href="#">ocean_core/ocean_velocity</a> <a href="#">advect.F90 [../src/mom4/</a> <a href="#">ocean_core/</a> <a href="#">ocean_velocity_advect.html]</a> <a href="#">ocean_core/ocean_grids.F</a> <a href="#">90 [../src/mom4/ocean_core/</a> <a href="#">ocean_core/ocean_topog.F</a> <a href="#">ocean_grids.html]</a> <a href="#">90 [../src/mom4/ocean_core/</a> <a href="#">ocean_topog.html]</a> <a href="#">ocean_core/ocean_freesur</a> <a href="#">f.F90 [../src/mom4/ocean_core/</a> <a href="#">ocean_freesurf.html]</a>	In addition to time average now users can have min, max in the same time period.
<a href="#">ocean_param/mixing/vert/</a> <a href="#">kpp/</a> <a href="#">ocean_param/mixing/neutr</a> <a href="#">ocean_vert_mix_coeff.F90</a> <a href="#">[../src/mom4/ocean_param/mixing/</a> <a href="#">vert/kpp/</a> <a href="#">ocean_param/mixing/neutr</a> <a href="#">ocean_vert_mix_coeff.F90</a> <a href="#">[../src/mom4/</a> <a href="#">ocean_neutral_physics.html]</a> <a href="#">ocean_tracers/ocmip2_biotic.html]</a> <a href="#">ocean_param/sources/spon</a> <a href="#">ge/ocean_sponges.F90 [../</a> <a href="#">src/mom4/ocean_param/sources/</a> <a href="#">sponge/ocean_sponges.html]</a>	Replace constant number 2 with parameter variable FATAL in error message.
<a href="#">shared/mpp_domains.F90</a> <a href="#">[../src/shared/mpp/</a> <a href="#">mpp_domains.html]</a>	Remove redundant mpp_clock for Ocean.
	using netcdf library to read and write data, instead of using mpp_io_mod.
	Added vertical interpolation. Add namelist do_laplace_extrap to improve efficiency when doing vertical interpolation.
	Added (len=*) for variable name in subroutine set_ocean_domain.
	Corrected bug identified by Pacanowski. For bottom partial cells with k=nk, the vertical advection of horizontal velocity was a factor of 2 too large. A mask has been added to correct this bug.
	Send to diagnostics for area_u had id_area_t in send_data, trivial bug.
	Added nml for flat_bottom for use in helping to debug problems related to bottom topography.
	Added nml option to have eta_t = 0.0 at the initial condition. This is useful when have restart files that have nonzero eta, and wish to debug without changing the restart files. Added nml option check_volume_conserve for debugging purposes.
	Removed the tidal_mix option as this remains a topic of research.
	Unified the calculation of the surface boundary layer. Now include information about the KPP boundary layer in the computation of the "neutral physics boundary layer".
	Corrected bug identified by John Dunne. Bug fix necessary to keep model from bombing.
	Removed code that inverted the input sponge coefficients. The input sponge_coeff NetCDF file should now give these coefficients in inverse seconds, rather than in seconds. Reasoning: (1) matches the documentation; (2) more intuitively linked to the name "sponge_coeff," with a large coeff implying a strong sponge; and (3) allows tapering of sponge coefficients to exactly zero.
	Bug fix for C grid case, does not affect MOM4 since MOM4 runs on B grid.

[mpp\\_update\\_domains2D.h](#)  
[../src/shared/mpp/  
mpp\_update\_domains2D.h]

Bug fix for C grid case, does not affect MOM4 since MOM4 runs on B grid.